Validation of MOPITT carbon monoxide and methane measurements using remote sensing by IR solar spectroscopy of moderate resolution combined with in-situ measurements.

(Final report)

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INTRODUCTION

The aim of the project is to validate the measurements of a gas-correlation space-based spectrometer MOPITT, which is a part of the EOS/*Terra* spacecraft. These activities are funded by Canadian and Russian funding agencies, as well as by NATO Scientific Program. *Terra* has been launched in December, 1999 and started to measure IR radiance from the Earth since March 8, 2000. This report presents first results of comparisons between spectroscopic ground-based and MOPITT space-based measurements of CO. Two ground sites are discussed, one in Russia and the other in Argentina. They have markedly different anthropogenic CO sources. The Russian site is an intra-continental site downwind of a strong Central European source of emission. A fast zonal transport effectively mixes CO, especially during the dark season when OH is depleted and CO has a longer lifetime. The Argentine site is located in a largely uncontaminated South Hemispheric region downwind from the Southern Pacific. However, there are areas with strong biospheric emissions of CO located to the North, e.g. the Amazon. For details see the paper which is to be submitted in early 2002(Yurganov et al., 2002).

Column amounts

MOPITT supplies the following standard data products: mixing ratios for selected pressure levels, namely, 850, 700, 500, 350, 250, 150 mb (i.e., profiles) and the total columns derived by integration of the profiles.

We first compared CO total columns (Fig. 1a and Fig. 2a) measured during the initial 13 months of MOPITT operation. We selected MOPITT data for the validation site coordinates (± 5 deg.) and for the dates of ground measurements (regardless of the time of the day) as well as for adjacent dates. We found a persistent 20% bias in the MOPITT data for the Argentine site and a significant range of disagreement for the Russian (Zvenigorod) site (from -20% to +20%). This disagreement in total column amounts likely stems from the difference in the vertical sensitivities of these two techniques. One should expect that MOPITT retrievals for the atmospheric layers with greater sensitivity to CO (the mid-troposphere) should be more precise than the total column retrievals, though we cannot validate them directly using the grating instruments.

As discussed earlier, the current version of the MOPITT retrievals is based on the thermal channels centered near 4.7 m. These channels rely upon emitted terrestrial and atmospheric radiation, and they show a drop in sensitivity to CO near the surface due to the low temperature contrast between the underlying surface and the lowest atmospheric layers. Consequently, direct comparisons between total column amounts measured by MOPITT and by the grating spectrometers might be reasonable only for cases of a well-mixed troposphere. It is therefore sensible to consider the mixing ratios retrieved for different layers.

Layer Mixing Ratios

The grating spectrometer has a substantial sensitivity spanning the entire tropospheric layer (which is assumed here to encompass altitudes between 0 and 10 km, or approximately 1000 – 250 mb). On the other hand, it is useful to consider the MOPITT data separately in terms of (i) a mean mixing ratio retrieved for the altitude range corresponding to 700 - 250 mb, (i.e., to the free troposphere) and (ii) the retrieved mixing ratio for the bottom layer (below 850 mb). In Figures 1b and 2b we show these mixing ratios as well as the mean tropospheric (0 – 10 km) mixing ratios derived from the grating data. Although these mixing ratios represent different atmospheric domains they shed some light on the discrepancy in total column amounts obtained: the first ratio turns out to be far more reliable than the second.

Over Russia (Fig. 2b), relatively good agreement was found between the MOPITT free troposphere and the grating data sets for the period from June to September 2000 (in both cases mixing ratios were found to lie between 90 and 100 ppb for the seasonal minimum). For the colder period of the year (March-April of 2000 and November 2000- April 2001), the free tropospheric mean CO mixing ratio was less than the total tropospheric mean (120 ppb and 160 ppb, respectively).

These results can be better understood by considering CO measurements made in Alaska during 1995 [Yurganov et al., 1998]. Then, a grating spectrometer (the instrument now installed in Argentina) measured CO spectra over Fairbanks, concurrently with direct measurements by D. Jaffe (University of Alaska Fairbanks) in the surface layer at the Poker Flat Range (30 km apart). Continuous data for CO in Barrow, Alaska (appr. 700 km to the North), conducted by CMDL were available as well (Fig. 3). We see that in March-May, 1995, CO mixing ratios for the entire troposphere were in the range 140-160 ppb with surface layer values near 180 ppb. Beginning in May the two data sets converged and dropped down to 90 ppb with just one spike in the tropospheric average in July (attributed tentatively to forest fires). The authors concluded that due to effective horizontal air mixing, the polluted atmospheric boundary layer spreads over Alaska and most likely over the entire Northern Hemisphere; the pollution accumulates during November - February and is removed by hydroxyl during the springtime also in the whole hemisphere. The surface measurements agreed with column measurements when the atmosphere was well mixed, and diverged in polluted boundary layer conditions.

This seasonal pattern quantitatively agrees with that observed in 2000-2001 over Zvenigorod. MOPITT mid-tropospheric measurements agreed well with grating column measurements during well-mixed conditions, and underestimated CO during polluted boundary layer conditions.

Considering now the retrieved MOPITT bottom layer mixing ratios, they proved to be close to reasonable values (around 200 ppb) in March -April, but were too high in the summer time. This is a result of the shape of the MOPITT a priori profile. Since the MOPITT thermal channels are not strongly sensitive to the bottom layer, the current bottom layer retrievals are dominated by the assumed a priori profile. This profile is realistic for winter-spring, but does not reflect the well-mixed tropospheric conditions often encountered in the summertime. These bottom layer retrievals are expected to improve significantly once the CO solar channel data are incorporated, but the current MOPITT retrievals are not very sensitive to lower tropospheric conditions.

A very different picture emerged in the SH. Over the Valdes Peninsula station (Fig. 2b), mixing ratios measured by MOPITT followed the seasonal cycle measured by the grating spectrometer, but with a mean difference of 17%. The MOPITT free tropospheric mean was 69 ± 9 ppb, and the grating tropospheric mean was 58 ± 10 ppb for the period of measurements. MOPITT mixing ratios for the bottom layer (1000-700 mb) were much higher than the grating tropospheric mean (up to 200% higher for some days).

To understand these results, we consider some preliminary data from surface measurements at the Tierra-del-Fuego NOAA/CMDL station (54 S, 68 W), located 1300 km to the South of the Valdes site (this was the nearest NOAA/CMDL site for surface CO measurements). These surface data show mixing ratios close to the lowest concentrations obtained by the grating spectrometer, suggesting no, or perhaps even a slightly positive, vertical gradient of CO with altitude. MOPITT indicates much higher CO concentrations for the bottom layer than these surface measurements, and a strongly negative vertical CO gradient. We therefore attribute the bulk of the discrepancy between MOPITT and the grating spectrometer to the insensitivity of MOPITT to the boundary layer. Lacking this sensitivity, the MOPITT retrievals revert primarily to the assumed a priori profile. (MOPITT uses the same profile for all latitudes). While this profile is representative of NH winter conditions, it is not typical to see such enhanced boundary layer CO levels in unpolluted SH sites.

Additionally, some part of the 17% difference between free tropospheric (MOPITT) and whole tropospheric (spectrometer) mixing ratios may be attributed to the positive vertical gradient in CO concentrations typically found in the SH troposphere. For example, our standard profile, based upon measurements taken near Australia (Francey et al., 1999), yields mean CO mixing ratios of 51 ppb for the whole troposphere and 56 ppb for the free troposphere, ie. a 10% difference. Moreover, a significant transport of CO from biomass burning in the north down to Patagonia, via the free troposphere, may enhance this effect.

From these Russian and Argentine comparisons, it appears that MOPITT is likely providing accurate (within ± 10%) middle tropospheric CO retrievals. Its lower tropospheric, and therefore its total column, retrievals are not yet reliable since current MOPITT retrievals are not strongly sensitive to the lower troposphere. It is expected that once the solar channel data is included that this shortcoming will be overcome.

Conclusions

The first data obtained by the MOPITT instrument between March 2000 and April 2001 have been compared to CO total column amounts independently measured by two grating spectrometers in Russia and Argentina. The MOPITT data successfully reproduce both seasonal and latitudinal CO variations. Total column amounts measured by MOPITT in the NH differ from those measured by ground-based instruments by ± 20%, depending on the season. MOPITT data exceed ground-based total column measurements in the SH by 20% throughout the year. These differences were attributed mainly to insufficient sensitivity of the satellite instrument to the bottom atmospheric layer (the boundary layer). MOPITT mixing ratios averaged over the free troposphere (700 - 250 mb) are more reasonable, and seem to lie within the target accuracy of ± 10 %. Upcoming improvements (primarily adding the solar channels) are expected to improve the MOPITT retrievals. In the meantime, the available BETA version provides free tropospheric CO concentrations to an accuracy of at least 10%. It is recommended, however, for better reliability, to consider free tropospheric partial columns instead of the concentrations reported separately for individual layers.

References

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Figure captions

Figure 1. a) A comparison between CO total column amounts determined by the grating spectrometer and MOPITT for the Zvenigorod station (Russia). MOPITT data are given for days of ground-based measurements +/- 1 day, for the station location +/- 5 deg. of latitude and +/- 5 deg. of longitude.
b) The same as a), but are plotted mixing ratios averaged over altitudes ranges where these instruments have substantial sensitivities; 250 - 1000 mb (spectrometer) and 250 -700 mb (MOPITT); also are shown mixing ratios retrieved from MOPITT data for the bottom layer, centered near 850 mb.

Figure 2. The same as Fig. 8, but for the Valdes Peninsula station (Patagonia, Argentina). Note a break in the horizontal axis (there were no measurements during that period).

Fig. 3. Measurements of 1995 in Alaska. The grating spectrometer was set up in Fairbanks and measured CO concurrently with in-situ ground-based sensors in Poker Flat Range (30 km from Fairbanks) and in Barrow (700 km from Fairbanks). Spectroscopic data, published by Yurganov et al. [1998], were reprocessed using the fitting technique, line parameters and a priori profiles used in this paper.

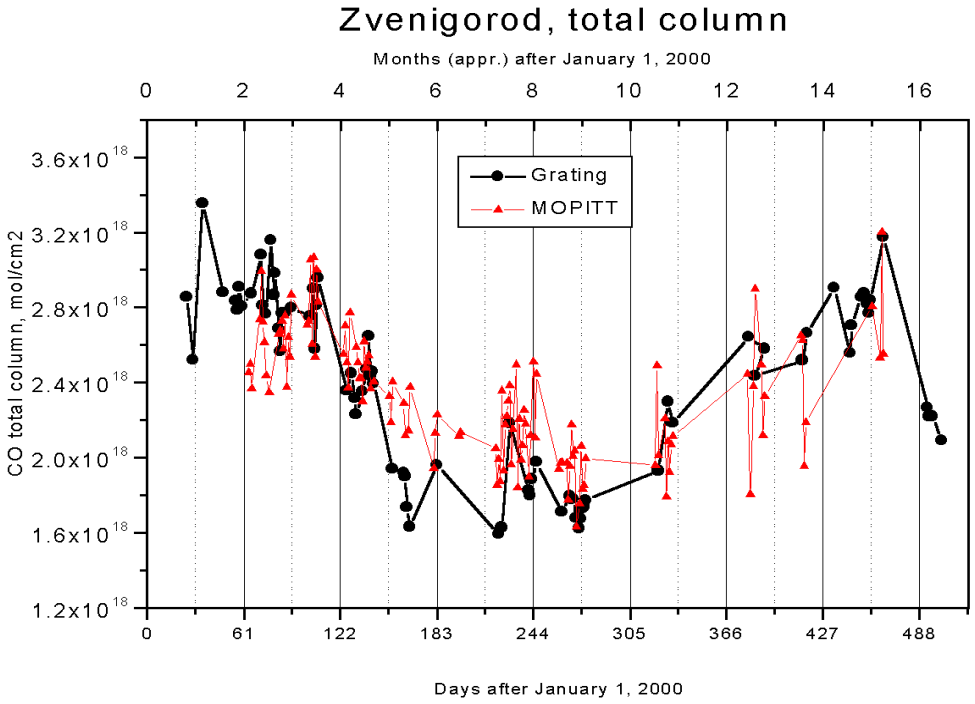

Figure 1a

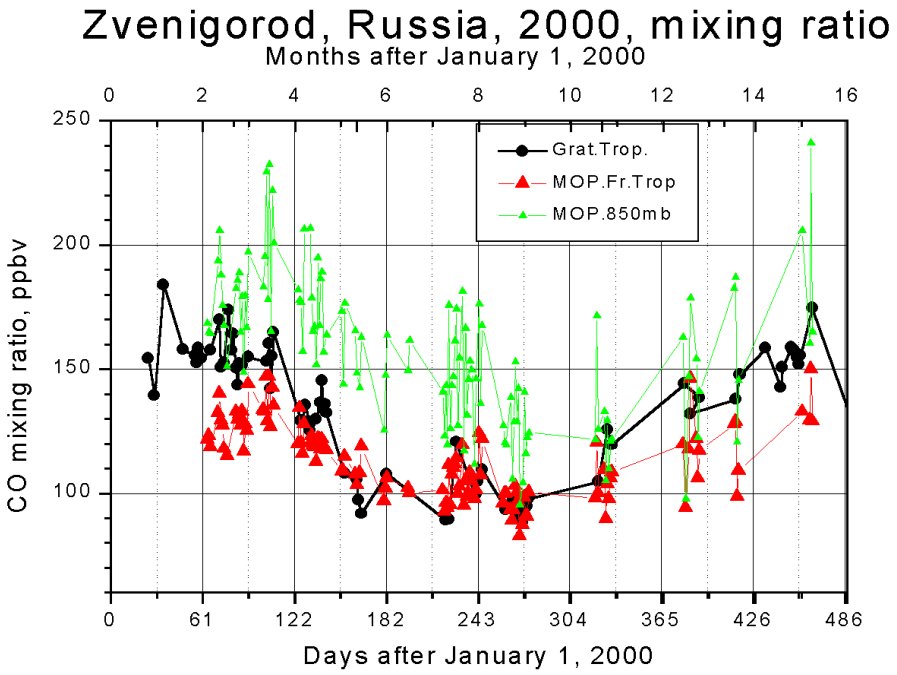

Figure 1b

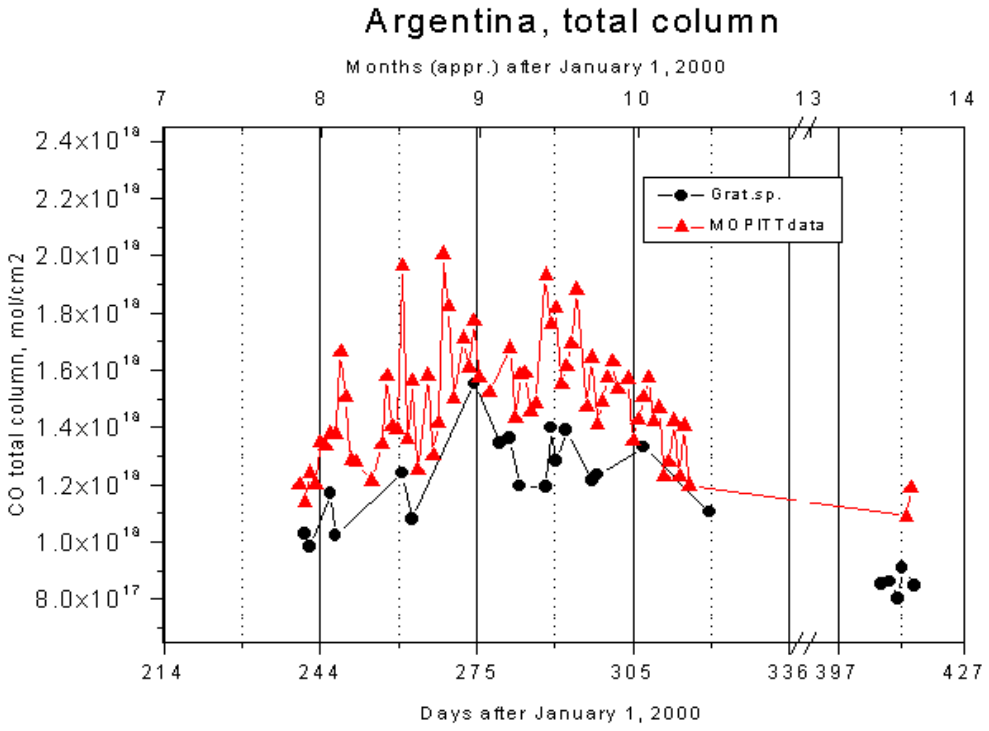

Figure 2a

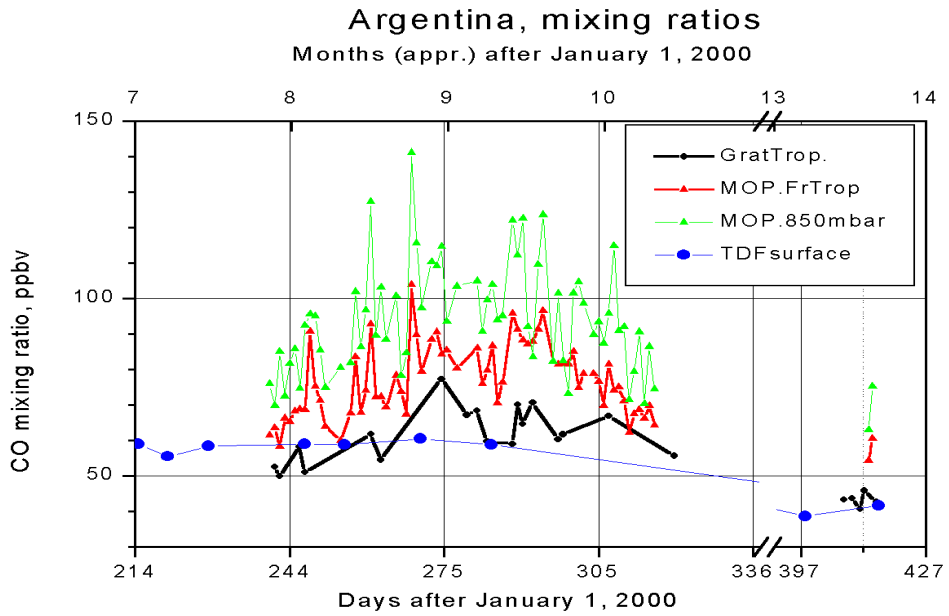

Figure 2b

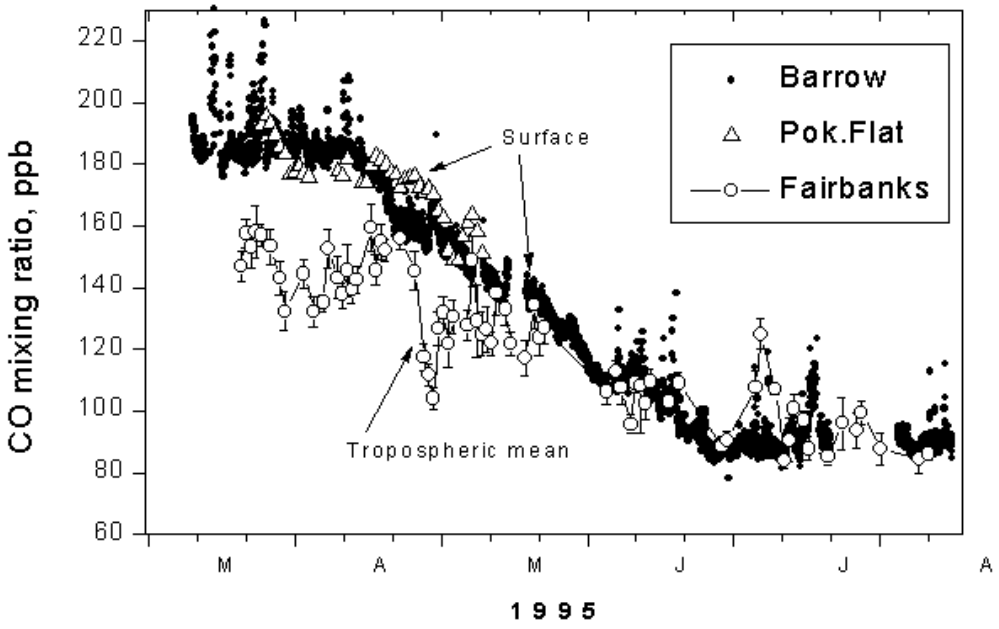
CO mixing ratio, ppb
220
200
180
160
140
120
100
80
60
M
A
M
J
J
A
1995
Barrow
Pok.Flat
Fairbanks
Surface
Tropospheric mean

Figure 3